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Study on the influence of dust on CO/H_2 deflagration characteristic

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Abstract

CO/H_2 mixture gas may be generated in the local furnace hopper area under the condition of coal quality variation, and deflagration may be caused during the high temperature coke dropping process. As for the complex dust environment of furnace hopper area, the influence of dust of different categories, particle size and concentration on CO/H_2 deflagration characteristics under the half-opened environment is studied in this paper. The study indicates that: the influence of dust on CO/H_2 deflagration feature mainly results from the release of volatile in dust and the volatile's participation in deflagration reaction. As for high volatile coal dust, volatile releases out and participates in deflagration reaction, which makes the deflagration overpressure of mixture gradually rises with the rising of volatile content; as for low volatile coal dust, the influence of heat absorption for volatile release is greater than the function in which volatile participates in deflagration reaction, thus reducing the deflagration strength. As for Yinbei coal, with the increase of dust concentration, deflagration strength declines firstly and then increases. Experiment also indicates that as for coke dust nearly without volatile, the change of deflagration intensity with dust concentration is not obvious.

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Keywords: deflagration; dust; CO; H_2; boiler

1. Introduction

The yearly electricity generating capacity in China is 4,721.7 billion kW·h in 2012, of which thermal power generation takes up 82.54% of the gross generation, and thermal power is still the leading power generation form in China [1]. Procurement cost of fuel takes up above 70% of the gross production cost for coal-fired power plant, so the instability of coal supply leads to the deviation of the actual coal quality for combustion with the designed coal

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quality. The deviation of the coal quality leads to ignition delay, increase of carbon content of ash and serious slagging of heating surface [2,3]. With the dropping of slag attached to heating surface into the furnace hopper, flammable gas may be generated through gasification reaction and leads to local deflagration [4,5].

Compared with ordinary environment, there are massive CO_2, N_2 and other explosion suppression gases and dust of high concentration in the furnace hopper. Sufficient study on the influence of different gases on deflagration feature has been done during our previous research [4]. The article mainly analyzes the influence of dust on deflagration feature of CO and H_2.

Wang Yude [6], Qu Zhiming [7] and Bi Mingshu [8] did the experimental research on methane-coal dust mixture explosion and discovered that when coal dust was added little, the mixture had lower deflagration pressure and velocity, in deflagration state; while when the concentration of coal dust rises to 368g/m^3, the mixture presented stable denotation state. Within certain particle size scope, the deflagration pressure and flame spreading speed increased with the decrease of coal dust particle size; under the optimal proportion, compared with methane-air and coal dust-air mixture, the deflagration pressure and velocity of the mixture of methane-coal dust-air increased obviously. Lui Yi [9] and Zhang Yinhe [10] studied the change of methane-coal dust mixture's lower deflagration limit respectively. Research showed that if the ratio of methane in the entire mixture or the content of volatile in coal dust was increased, the lower deflagration limit might decline obviously; the particle size of coal dust has little influence on lower deflagration limit. Khalil [11] made research on the influence of ash mixed with active carbon on the deflagration parameter of hydrogen/air mixture. His research indicated that: the deflagration pressure rising rate and maximum pressure produced by all mixtures with ash and hydrogen under whatever concentration proportion are greater than the deflagration parameters of single hydrogen/air mixture. D Castellanos [12] studied the influence of particle size dispersity on the dust deflagration strength, and discovered that with certain size scope, the higher size dispersity of particle was, the higher the overpressure of deflagration was.

Researches on deflagration feature of gas-dust mixture mainly focus on methane-coal dust mixture and have obtained meticulous research achievements. However, the deflagration feature between CO/H_2 gas and coal dust, coke dust, coal ash which are typical in furnace hopper area are still lack of meticulous research data. The influence of different dust categories, particle sizes and concentration on CO/H_2 deflagration feature were studied experimentally and it will have certain guidance on prevention of the deflagration in furnace hopper.

2. Experiment

2.1. Experiment system

The experiment system was vertically installed including gas distribution system, dust supply system, ignition system, deflagration tube and measurement system(seen Fig. 1). The dimension of upside deflagration tube was Φ42×3×1,000mm and the dimension of lower deflagration tube was Φ60×3.5×1,000mm. Three DYTRAN-1,300V piezoelectric pressure transducers were uniformly equipped at the lower segment of tube, with sampling frequency at 500 kHz and sensitivity at 10mV/PSI (±5%). The data collection system was DEWE-1201 data collection system with the highest sampling rate at 100 kHz.

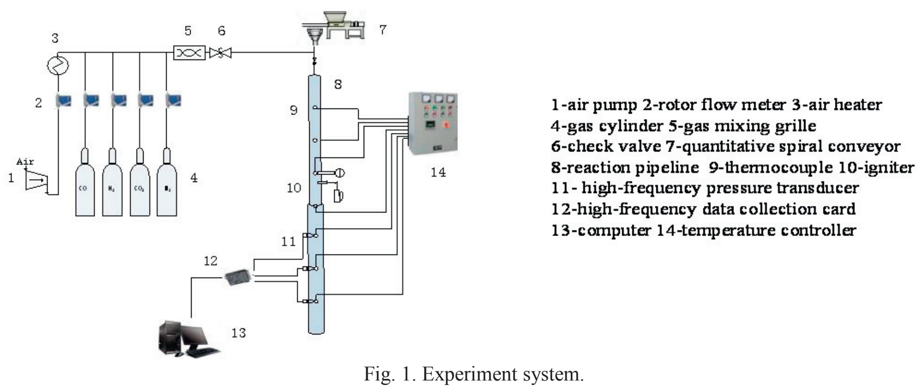

Fig. 1. Experiment system.

2.2. Experimental condition

2.2.1. The influence of dust category on deflagration feature

In order to compare the different influence of dust categories on the deflagration feature of gas-dust mixture, three kinds of coal dust, a kind of coal ash and a kind of coke dust were selected as experiment samples. The industrial analysis of the three kinds of coal dust is seen in Table 1. The coke dust was made from Yinbei coal in drop-tube furnace under the environment of N_2 and temperature of 1300℃.

Table 1. Industrial analysis of the coal sample (%).

Inspection name	Moisture M_{ad}	Ash A_d	Volatile V_{daf}	Fixed carbon FC_{ad}	Sulfur $St_{,d}$	$Q_{net,ar}$
Mengxi coal	16.77	10.38	38.92	45.56	1.16	16.7
Ningdong coal	9.32	23.69	34.12	45.59	0.2	20.2
Yinbei coal	0.56	35.56	26.53	47.08	1.01	19.05

2.2.2. The influence of particle size on deflagration feature

Particle size analysis was done on the dust sampled from the furnace hopper of boiler in a power plant. Particle size scopes of this experiment were selected as 50-80μm, 80-160μm and 160-200μm based on the size analysis result.

2.2.3. The influence of dust concentration on deflagration feature

The dust concentration in furnace hopper is about 10-20g/m^3， so the dust concentration scope of this experiment was set as 3-35g/m^3.

3. Results and analysis

3.1. The influence of dust category on deflagration intensity

Fig. 2 indicates the influence of different dust categories on deflagration overpressure and its maximum rising rate. Particle size of the five kinds of dust in Fig. 2(a) are both 50-80μm and the volatile content falls by order from left to right. Comparing the three kinds of coal dust, with the declining of volatile content, the deflagration overpressure gradually declines. The deflagration intensity under ash condition could maintain in higher level, while the addition of coke dust would reduce deflagration intensity to some extent. Besides, the deflagration overpressure at three measuring points rises firstly and then declines no matter what kind the dust is, which reflects the aggregation and releasing process of pressure in tube. Then the maximum pressure rising rate of three kinds of dust are illustrated in Fig. 2(b). Similar to tendency of overpressure, the maximum pressure rising speed under the function of ash is highest up to 180MPa/s, the second is coke dust, and coal dust is the lowest at about 65MPa/s. The maximum pressure rising rate at three measuring points rises by order, which is different from the tendency of deflagration overpressure.

The influence of dust categories on CO/H_2 deflagration mainly results from different volatile content in dust. For the dust with lower volatile content, such as ash, there is nearly no volatile release during deflagration process and the heat absorption is little so that the deflagration intensity could maintain at higher level; for dust with higher volatile content, the release of volatile will absorb massive heat and lead to the declining of deflagration intensity, but with the rise of volatile content, more and more volatile re-participates in the combustion reaction and the deflagration overpressure gradually rises again.

3.2. The influence of particle size on deflagration intensity

Fig. 3 indicates the influence of different particle sizes of coal dust on deflagration overpressure and its maximum rising rate. It is seen from the figure that the deflagration overpressure and its maximum rising rate will decline with the decreasing of particle size. Because the less particle size is, the easier the volatile release and the more heat are absorbed in the fast deflagration reactions, and then its influence on deflagration intensity is more obvious.

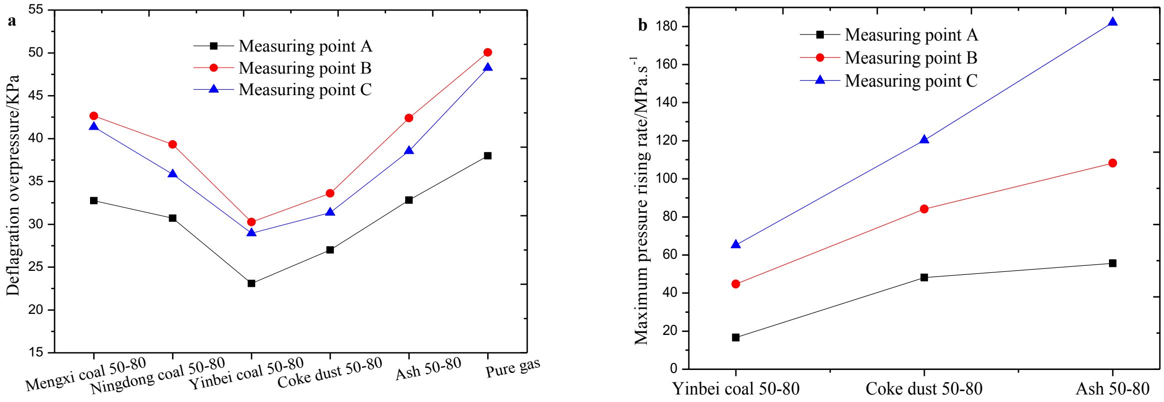

Fig. 2. The influence of dust category on deflagration intensity (a) Deflagration overpressure (b) Maximum pressure rising rate.

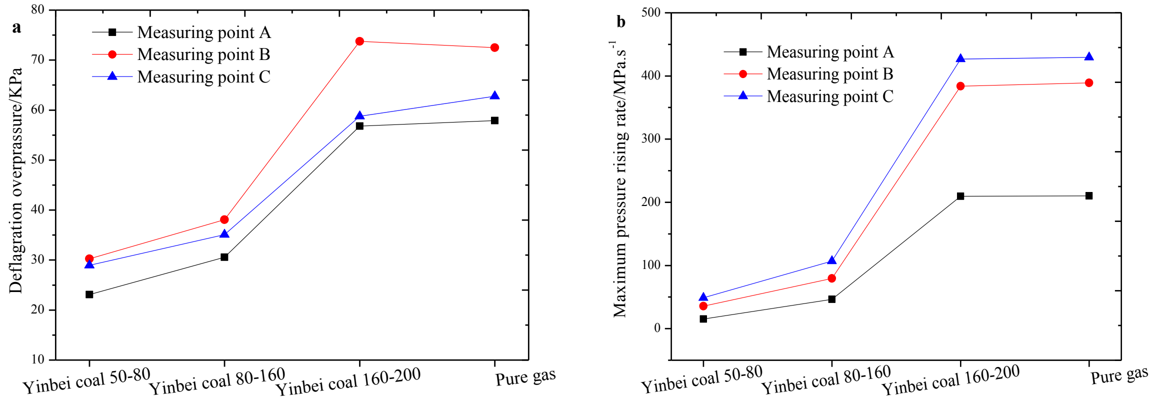

Fig. 3. The influence of particle size on deflagration intensity (a) Deflagration overpressure (b) Maximum rising rate of pressure.

Hu Shuangqi [13] discovered that with the decrease of particle size, the deflagration pressure and its rising rate will increase in his study on deflagration feature of superfine coal dust in closed pipeline, and his test results are different from ours. Given that on one hand, the dust particle size used in our study is much bigger than superfine dust, so the deflagration of the gas-dust mixture under weak ignition condition is ignited by the combustion of gas fuel rather than dust particles direct initiation introduced by previous scholars. On the other hand, due to the half-opened experiment tube, partial released volatile could not participated in deflagration reaction and has been pressed out of tube by deflagration wave. This is also one of reasons for the lower deflagration overpressure in our experiment.

3.3. The influence of dust concentration on deflagration intensity

The relations of maximum deflagration pressure rising rate with dust concentration in dust-CO/H_2 mixture at different dust categories are seen in Fig. 4. As for coal dust with particle size at 50–80μm, with the dust concentration rising from $4g/m^3$ to $34.1g/m^3$, the deflagration overpressure decreases firstly and then rises. When the dust concentration is $15g/m^3$, the maximum pressure rising rate reaches the minimum value at about 3.2MPa/s; as for coal dust with particle size at 80–160μm, with the increase of dust concentration, similarly the maximum deflagration pressure rising rate presents the U-type tendency of first declining and then rising, and reaches the minimum value of 4.1MPa/s at the concentration of about 11.5g/m^3. Fig. 4(c) is the tendency of maximum pressure rising rate with different dust concentration of coke dust with particle size at 50–80μm. It indicates that with the increase of dust concentration, the maximum pressure rising rate fluctuates without obvious trend.

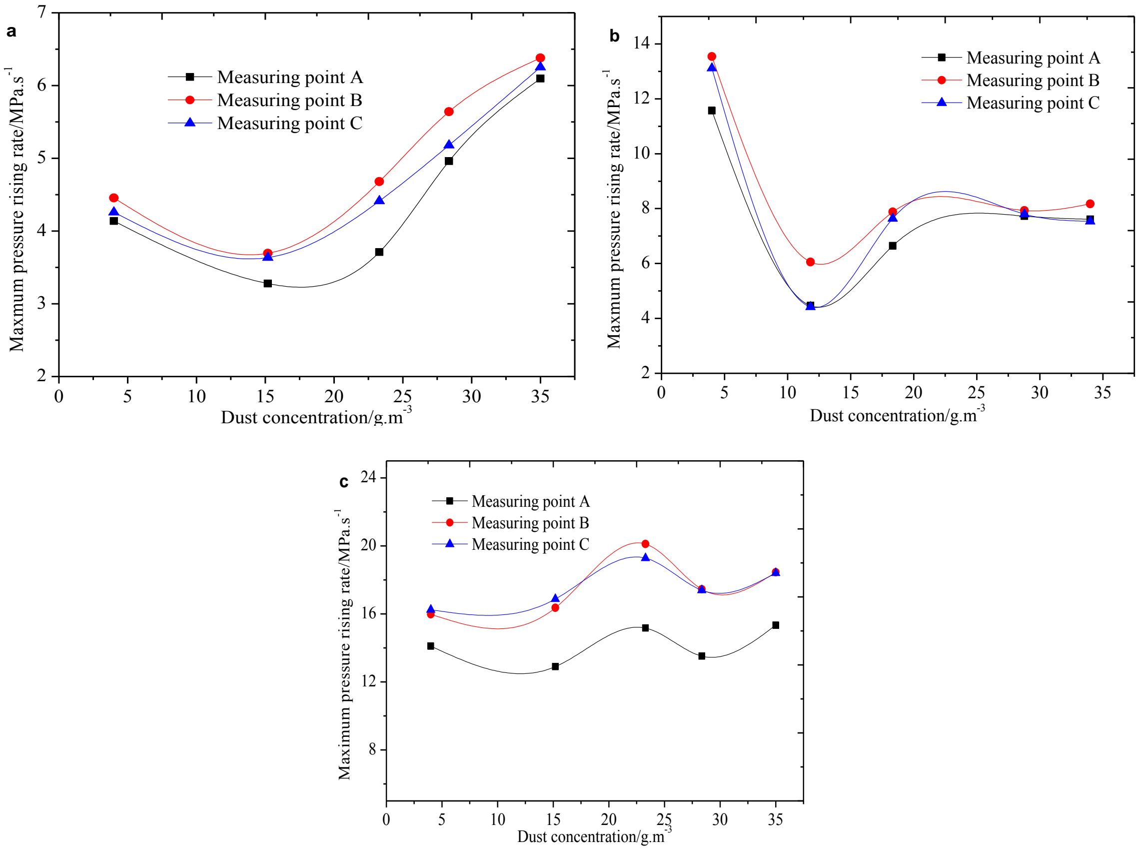

Fig. 4. The influence of dust concentration on the maximum pressure rising rate (a) 50-80μm coal (b) 80-160μm coal (c) 50-80μm coke

The U-type tendency of declining and rising for the maximum pressure rising rate can be explained as that: when dust concentration is lower, the released volatile during the deflagration process requires little heat, and the heat released from gas combustion could maintain the deflagration intensity at higher level; while when the dust concentration increases to certain degree, although dust particles absorb certain heat for volatile releasing, volatile re-participates in deflagration reaction and increases the deflagration intensity. These two competitive impacts make the pressure rising rate present U-type curve with the increase of dust concentration. The minimum value of 50-80μm coal dust curve has higher dust concentration than that of 80-160μm coal dust curve, which indicates that in the competition between heat absorption of volatile release and the re-participation of volatile in deflagration reaction, the heat absorption takes the leading position. The unobvious change of coke dust is the result of the lower volatile content in coke.

3.4. The influence of dust on gas lower deflagration limit

Fig.5 indicates influence of coal dust, coke dust and ash on H_2 lower deflagration limit (LDL) under 10vol% of CO_2. Seen from the Fig., compared with pure gas, added of coal dust results in light increase in LDL of hydrogen, addition of ash has little impact on its LDL, while coke dust leads to obvious reduction on LDL, namely that compared with coal dust and ash, coke dust makes the mixture easily into deflagration area. The reason is that during the process of spark ignition, with the added of coal dust, heat absorption for volatile release reduces heat accumulation between the electrode of spark plug so as to raise lower deflagration limit. And the pore structure of coke dust can promote heat accumulation between electrodes to lower the LDL. Volatile of ash is lower and its structure is not poriferous, therefore there is little influence on the lower deflagration limit.

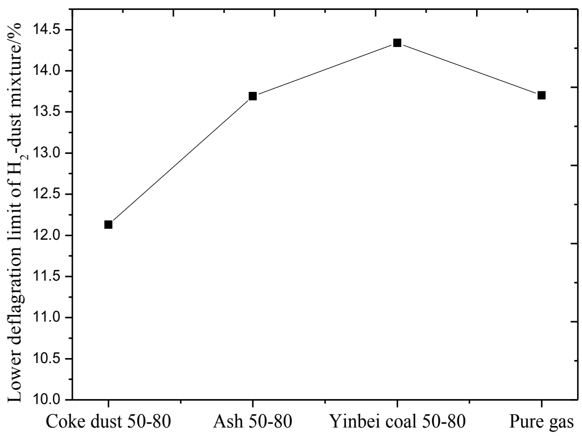

Fig. 5. Influence of dust category on lower deflagration limit

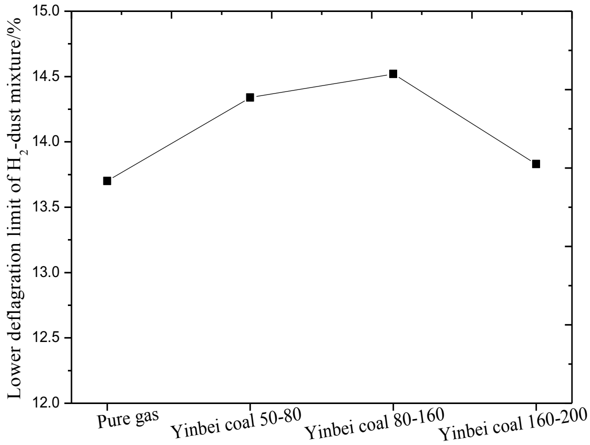

Fig. 6. Influence of coal particle size on lower deflagration limit

Fig. 6 indicates the influence of coal particle size on lower deflagration limit. It is founded that compared with pure gas, lower deflagration limit of hydrogen under coal dust with different particle sizes raises slightly. Within the three size scopes, 160-200μm of Yinbei coal dust has the minimum effect on LDL. It is because that coal dust does not nearly involve in the reaction under this larger particle size. For Yinbei coal with smaller size of 50-80μm, during the ignition, volatile of low ignition energy releases rapidly and this volatile reduces the minimum ignition energy of mixture obviously, and increases the possibility to explode. Thus, though a lot of heat is absorbed, the lower deflagration limit does not changed obviously. For coal dust of 80-160μm, a little volatile release absorbs heat but it cannot result in the reducing of minimum ignition energy of the mixture, so that its lower deflagration limit is highest

4. Conclusions

Under the condition of weak ignition in semi-open tube, the influences of dust on gas deflagration features are as follows:

- With the same particle size, for coal dust with higher volatile content, with the increase of volatile content, the deflagration intensity gradually rises; as for low volatile dust like ash, it would not involve in deflagration reaction and the deflagration intensity can keep at higher level.
- As for Yinbei coal, it is founded that: As the particle size reduces to 50μm, the deflagration intensity gradually recedes. With an increase of dust concentration from $3g/m^3$ to $35g/m^3$, the deflagration intensity of mixture rises firstly and then reduces; while coal dust with particle size larger than 160μm does not influence the deflagration intensity. It could be explained as the results of volatile release and involving in the deflagration reaction. As for high volatile coal dust, volatile releases and re-participates in deflagration reaction, and with the rising of volatile content, the deflagration intensity gradually rises; as for low volatile coal dust, the influence of dust heat absorption is greater than the effect of the participation of volatile in deflagration reaction, thus reduces the

deflagration intensity. It is also indicated that for ash and coke dust without volatile, changes in their deflagration intensity with dust concentration is not obvious.

- With the same particle size, coal dust results in light increase on lower deflagration limit and coke dust can reduce LDL, but ash does not influence obviously. It may be the result of heat absorption caused by volatile release and less heat dissipation between electrodes caused by coke pore structure.

Acknowledgements

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